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TURBULENT CHARACTERISTICS IN THE SURFACE BOUNDARY LAYER

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ATMOSPHERIC SCIENCES RESEARCH OFFICE
WHITE SANDS MISSILE RANGE, NEW MEXICO

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ABSTRACT

The turbulent characteristics of the first 62 meters of the atmosphere over White Sands Missile Range, New Mexico, have been intensively studied using data collected from an instrumented tower. It is demonstrated that important turbulence characteristics such as standard deviation of wind direction, longitudinal intensity of turbulence, and the ratio of the lateral intensity of turbulence to longitudinal intensity of turbulence are dependent upon the height of the wind measurement, the surface roughness, and the stability of the atmosphere.

In particular, it is shown that the lateral intensity of turbulence is affected more by stability changes than by roughness or height of the measurement. The longitudinal intensity of turbulence, however, is affected by roughness and height of measurement as well as by the stability of the atmosphere.

CONTENTS

INTRODUCTION

To predict the trajectory of unguided rockets or the diffusion of toxic contaminants accurately, the turbulent characteristics of the atmosphere must be known. The purpose of this paper is to present the results of an investigation of the turbulent characteristics from meteorological data gathered at White Sands Missile Range, New Mexico, on a 62-meter tower. The study was based upon the thermal structure of the atmosphere as classified by the stability in the form of the gradient Richardson number. A secondary parameter, the logarithm of the ratio of height of wind measurement to the surface roughness length, was coupled to the Richardson number to determine the effect of each of these parameters on the magnitude of atmospheric turbulence.

DATA COLLECTION AND REDUCTION

The meteorological data were collected at nine levels on the 62-meter tower at White Sands Missile Range, New Mexico, by the Atmospheric Sciences Office. The instruments were at heights of 4.6, 11.9, 19.3, 26.6, 33.9, 41.2, 48.5, 55.8 and 62.0 meters. The wind measuring instruments were Bendix Friez Aerovanes with a distance constant of approximately 5.0 meters, and the temperature sensors were aspirated thermocouples. More information on the details of the instrumentation has been published by Rachele and McLardie (1957). The wind data were recorded on Esterline Angus strip chart recorders, while temperatures were recorded on a Leeds and Northrop recorder. These wind data were collected on random days during a 25-month period covering April 1958 to April 1960. On data collection days 10-minute samples were recorded from each of the 9 levels every 3 hours beginning at 0100 continuing through 2200 local time. Five-second averages were calculated (from the 10-minute samples) yielding 120 samples for each 10 minute period for each level. A total of 1611 profiles were recorded.

After those profiles in which the mean wind was considered too light (less than 3 miles per hour) were discarded there remained 850 profiles that were used in this study. The temperature data were collected at a rate of one sample per 44 seconds and also used in 10-minute samples.

The site is characterized by an abundance of hillocks spaced 6 to 10 meters apart and approximately 1 to 5 meters high, with a surface roughness length of 0.2 meters (Hansen, 1967).

DISCUSSION AND RESULTS

The results presented here reflect statistics over a 10-minute interval. It is recognized that sampling interval, sampling length, and instrumental characteristics all influence the variances about the mean velocities. For example, the length of the sample will determine the low frequency contribution to the total variance, whereas instrument response characteristics determine the high frequency contribution to the variance.

In Figure 1, it is seen that the standard deviation of wind direction can be estimated from a mean wind speed once an estimate of stability is made. The figure, valid to a height of 62 meters, is consistent with Lumley and Panofsky (1964) who stated that under neutral conditions σ_A was of the order of 5 degrees and in unstable conditions, between 10 and 20 degrees.

A similar approach was attempted for estimating the standard deviation of wind speed (σ_u). It was found that there was too much scatter in the data to permit a simple estimate of σ_u from a mean speed, indicating that other factors had to be considered.

Figure 2 relates σ_A to the stability of the atmosphere in the form of a Richardson number (Ri) and the logarithm of the ratio of the height (z) at which the wind measurement is made and the surface roughness (z_o) Six stability regimes are shown:

1. Windless convection $Ri < -.100$
2. Free convection $-.100 < Ri < -.020$
3. Forced convection $-.020 < Ri < -.001$
4. Neutral $-.001 < Ri < .001$
5. Stable $.001 < Ri < .15$
6. Undulant $Ri > .15$

The central values of Richardson number (Ri) in regimes 2,3,4, and 5 were plotted on the abscissa in Figures 2,3, and 4. The data appear to uphold the findings of Prasad and Panofsky (1967) and Smith and Abbott (1961) in that σ_A appears to depend largely on stability under unstable to near-neutral conditions. Beyond near-neutral conditions, there is a decrease in σ_A as stability increases, with an increase in σ_A as stability conditions approach the undulant regime. The probable cause of this increase is σ_A is that under undulant conditions wind speeds

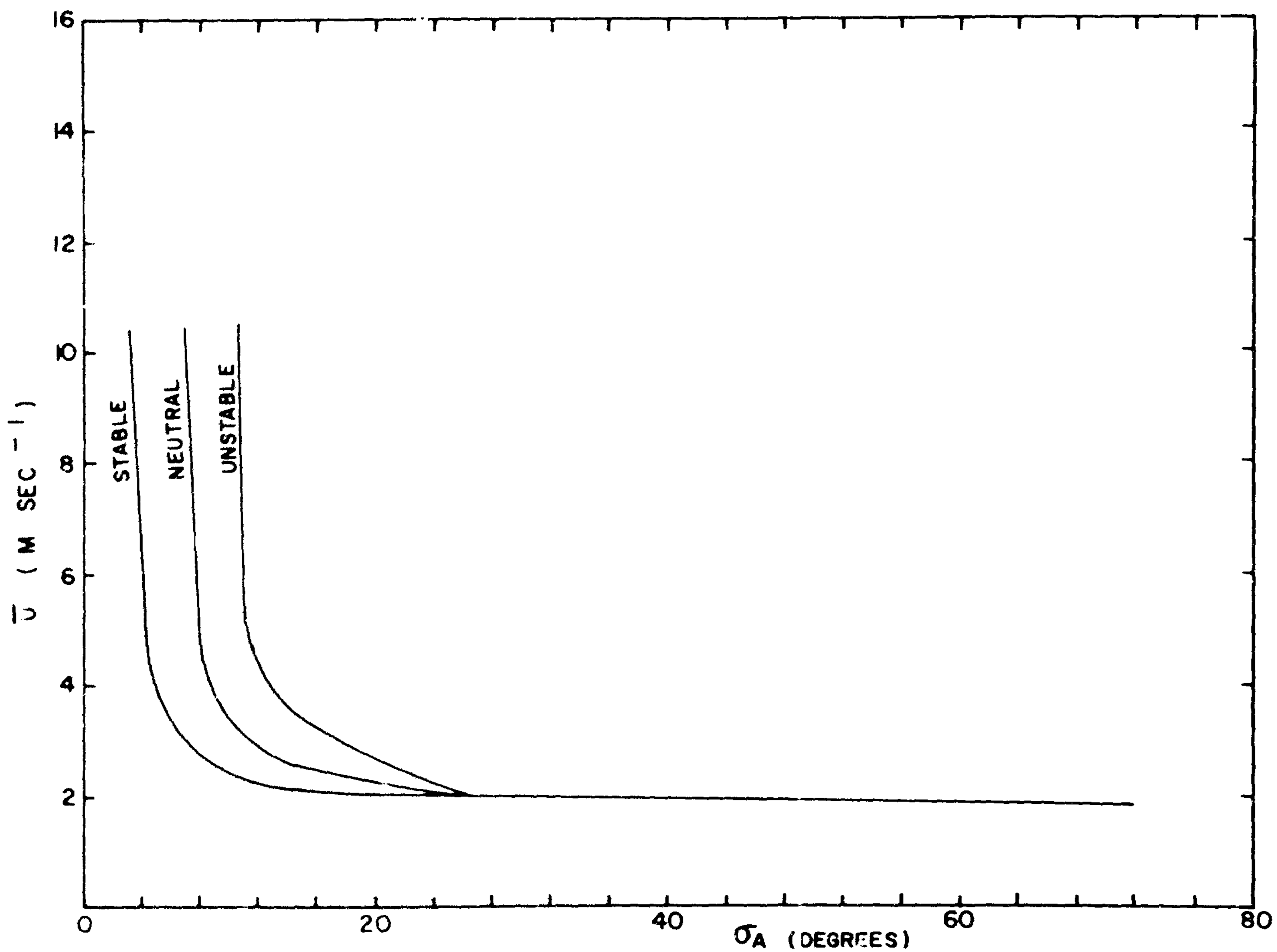

FIG. 1 RELATIONSHIP OF THE STANDARD DEVIATION OF WIND DIRECTION TO MEAN WIND SPEED.

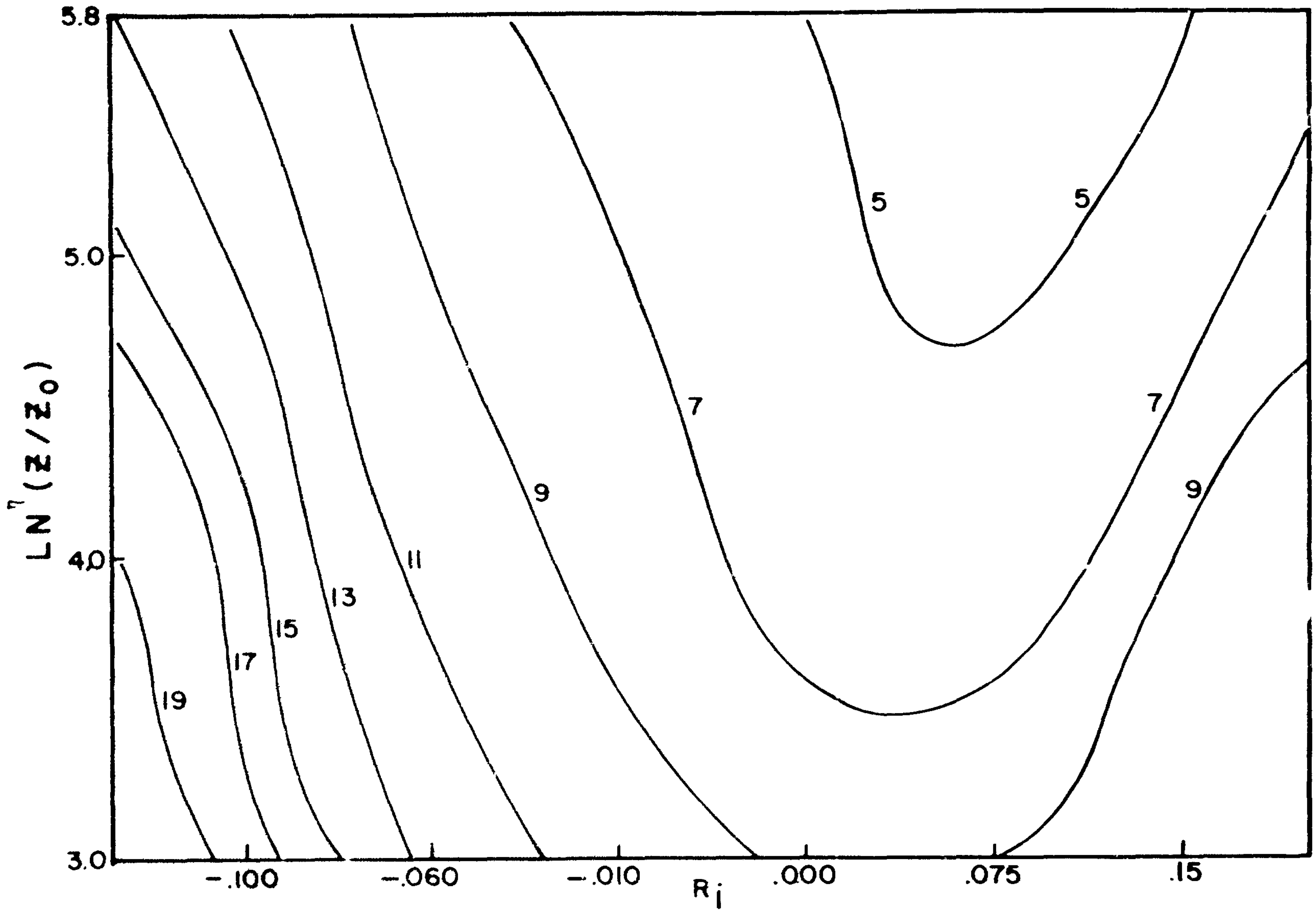

FIG. 2 STANDARD DEVIATION OF WIND DIRECTION (degrees) AS A FUNCTION OF R_i AND Z/Z_o

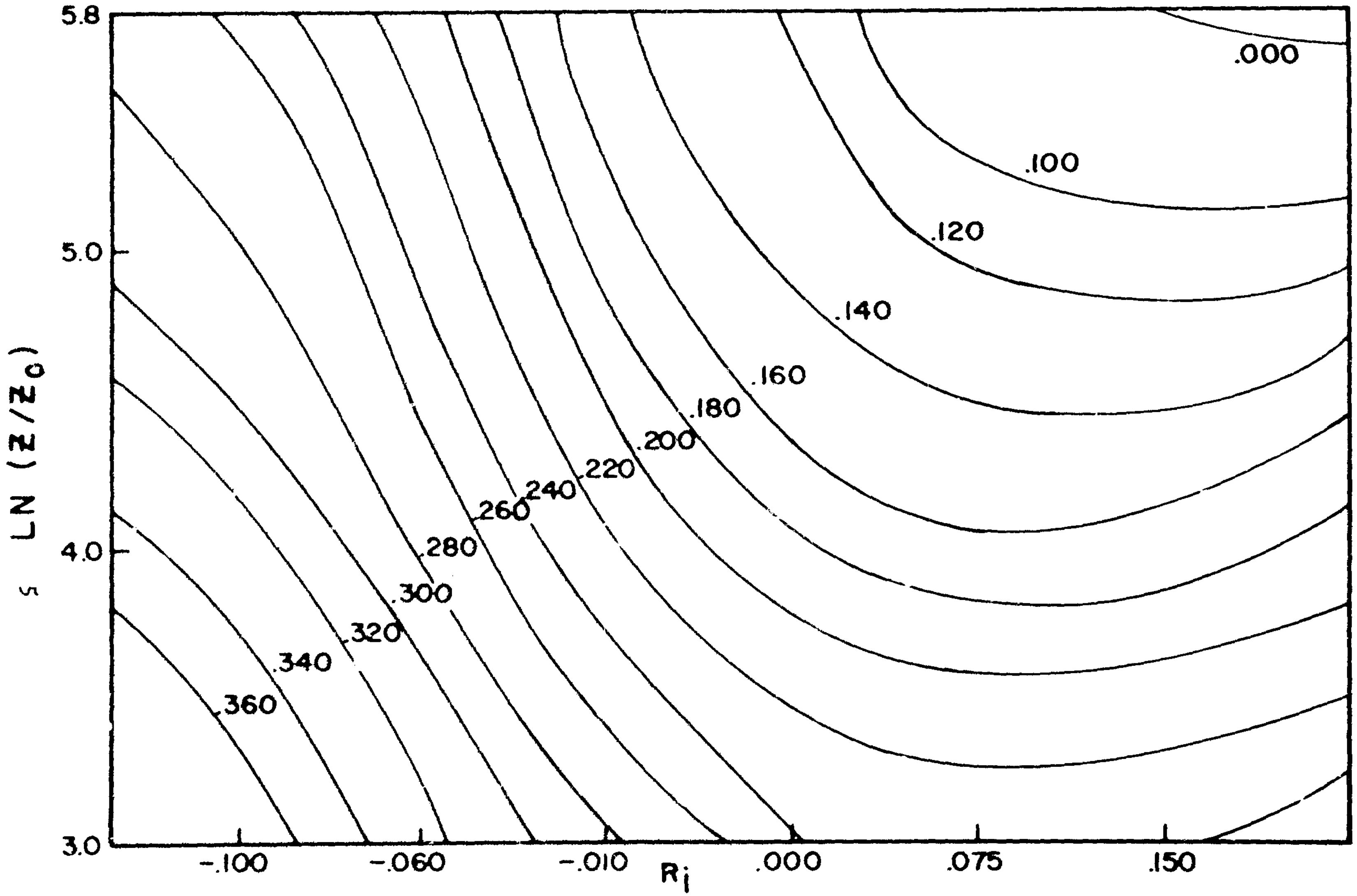

FIG. 3 LONGITUDINAL INTENSITY OF TURBULENCE AS A FUNCTION OF R_i AND Z/Z_o

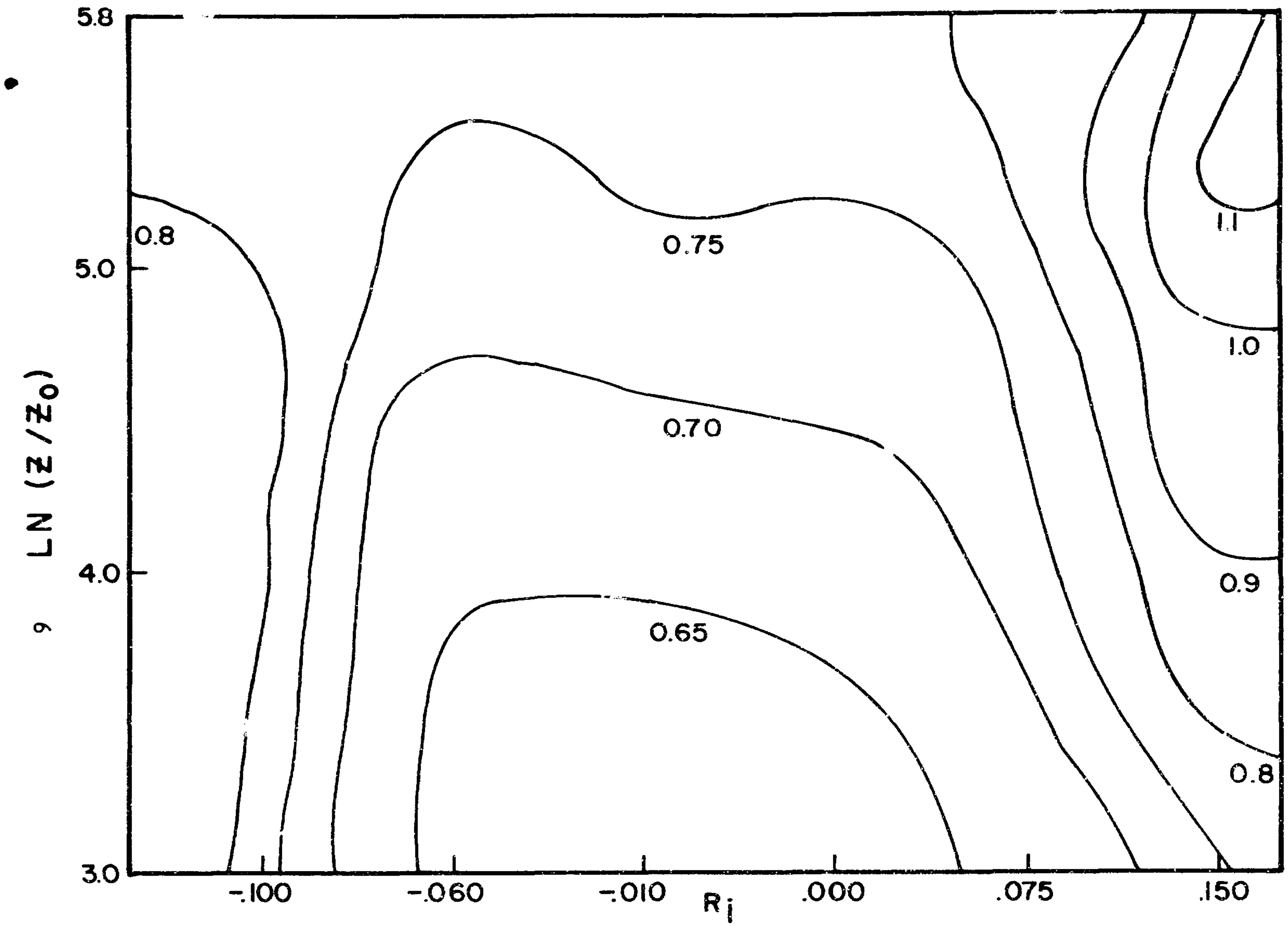

FIG. 4 RATIO OF LATERAL TO LONGITUDINAL INTENSITY OF TURBULENCE AS A FUNCTION OF R_i AND Z/Z_o

are generally light and wind direction fluctuations are quite large.

It is thus possible with Figure 2 to estimate the standard deviation of the wind direction at a given height once a roughness length and stability regime are determined.

Figure 3 clearly shows the dependence of the intensity of longitudinal turbulence $\frac{\sigma_u}{\bar{V}}$ on stability, height of measurement, and surface roughness. The data show that for any given stability regime $\frac{\sigma_u}{\bar{V}}$ decreases with height more rapidly than σ_A. This is in agreement with Swanson and Cramer (1965) who found that under neutral conditions $\frac{\sigma_u}{\bar{V}}$ decreased faster with altitude than σ_A. The data, again as with σ_A, show a decrease beyond the neutral regime to the stable side, and then as stability approaches the undulant regime $\frac{\sigma_u}{\bar{V}}$ increases.

In Figure 4, an attempt was made to determine the relationship of the lateral intensity of turbulence to the longitudinal intensity of turbulence. The lateral intensity of turbulence was obtained from the σ_A where σ_A in radians = $\frac{\sigma_v}{\bar{V}}$ in accordance with Lumley and Panofsky (1964). Thus the ratio of the turbulent intensities as a function of the logarithm of $\frac{z}{z_o}$ and Ri should reveal the size of the lateral intensity of turbulence. It is apparent that $\frac{\sigma_u}{\bar{V}}$ is generally larger than $\frac{\sigma_v}{\bar{V}}$ except under undulant conditions where $\frac{\sigma_v}{\bar{V}}$ becomes equal to or larger than $\frac{\sigma_u}{\bar{V}}$ as height increases. It should be noted that $\frac{\sigma_v}{\bar{V}}$ approaches $\frac{\sigma_u}{\bar{V}}$ as height increases with the ratio being near 0.8 at the 62-meter height in the unstable to the neutral regime, becoming larger as stability increases.

CONCLUSION

A simple method of estimating the standard deviation of wind direction (σ_A) using a mean wind speed has been shown. Indications were that under stable conditions with winds greater than 4 meters second^{-1}, σ_A ranged from

4 degrees at the higher wind speeds to 5 degrees at the lower speed. Below a speed of 4 meters seconds^{-1} there is a sharp increase in σ_A as the mean wind speed decreases; the estimation of σ_A with wind speeds of 2 meters second^{-1} or less becomes unreliable due to the scatter of σ_A.

In addition, the dependence of the standard deviation of wind direction on height of wind measurement, surface roughness, and stability is demonstrated. Specifically, it is shown that it increases as stability changes from neutral conditions to windless convection. Moreover, σ_A decreases slightly beyond neutral conditions as stability increases. However, there is a sharp rise as stability approaches the undulant regime. Surface roughness and height of measurement do not appear to affect it as much as stability. In general σ_A ranges between 6 to 19 degrees as instability increases beyond neutral conditions and between 6 to 9 degrees as stability increases from neutral.

The longitudinal intensity of turbulence $\frac{\sigma_u}{V}$ appears to depend on stability as well as on height of measurement and surface roughness as instability increases from neutral to windless convection. Under neutral and stable conditions, surface roughness and height of measurement appear to affect $\frac{\sigma_u}{V}$ more than stability. In general, $\frac{\sigma_u}{V}$ decreases with increase in altitude and increase in stability in the unstable side to just past neutral conditions into the stable side. As the atmosphere approaches extremely stable conditions (undulant) there is a minor increase.

Finally, the ratio of the lateral intensity of turbulence to the longitudinal intensity of turbulence was related to the height of measurement, surface roughness and stability. In general, it was found that the longitudinal intensity of turbulence is larger than the lateral intensity of turbulence except near the 62-meter level under undulant conditions, where they are equal or $\frac{\sigma_v}{V}$ becomes slightly larger. The ratio values increase with altitude becoming approximately 0.8 at 62 meters.

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13. ABSTRACT
The turbulent characteristics of the first 62 meters of the atmosphere over White Sands Missile Range, New Mexico, have been intensively studied using data collected from an instrumented tower. It is demonstrated that important turbulence characteristics such as standard deviation of wind direction, longitudinal intensity of turbulence, and the ratio of the lateral intensity of turbulence to longitudinal intensity of turbulence are dependent upon the height of the wind measurement, the surface roughness, and the stability of the atmosphere. In particular, it is shown that the lateral intensity of turbulence is affected more by stability changes than by roughness or height of the measurement. The longitudinal intensity of turbulence, however, is affected by roughness and height of measurement as well as by the stability of the atmosphere.

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